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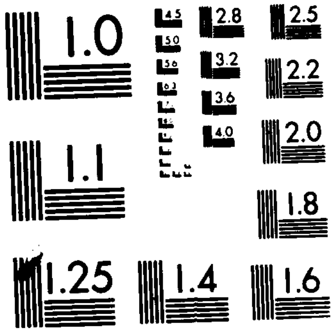

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FIRST WEATHER WING

TECHNICAL NOTE

CHARLES P. GUARD, MAJ, USAF

A STUDY OF WESTERN NORTH PACIFIC TROPICAL STORMS AND TYPHOONS THAT INTENSIFY AFTER RECURVATURE

This Technical Note examines the behavior of tropical cyclones which intensify after recurvature. The unexplained behavior has led to large intensity forecast errors. This study discusses the seasonal fluctuations of intensification after recurvature (IAR), the synoptic pattern associated with it, and the monthly characteristics of IAR as a function of the physical parameters in the tropical cyclone's oceanic and atmospheric environment.

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Contrary to the indications of several past studies, numerous tropical cyclones intensify after recurvature. The unexplained behavior has led to large intensity forecast errors. This study reveals two seasonal peaks of the behavior separated by a July minima in which intensification after recurvature (IAR) does not occur. A particular synoptic pattern is identified. Monthly characteristics of IAR are explained as a function of physical parameters in the tropical cyclone's oceanic and atmospheric environment. Guidelines are provided to allow the forecaster to anticipate and react to IAR.

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ABSTRACT

Contrary to the indications of several past studies, numerous tropical cyclones intensify after recurvature. The unexplained behavior has led to large intensity forecast errors. This study reveals two seasonal peaks of the behavior separated by a July minima in which intensification after recurvature (IAR) does not occur. A particular synoptic pattern is identified. Monthly characteristics of IAR are explained as a function of physical parameters in the tropical cyclone's oceanic and atmospheric environments. Guidelines are provided to allow the forecaster to anticipate and react to IAR.

This study was presented in part at the 12th Technical Conference on Hurricanes and Tropical Meteorology of the American Meteorological Society, 24-27 April 1979, Grand Hotel, New Orleans, Louisiana, under the title "The Intensity of Recurving Western North Pacific Tropical Cyclones: A New Look."

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A STUDY OF WESTERN NORTH PACIFIC TROPICAL STORMS AND TYPHOONS THAT INTENSIFY AFTER RECURVATURE

1. INTRODUCTION.

The intensity behavior of recurving tropical cyclones has long been a problem for the operational tropical cyclone forecaster. Riehl (1972) showed that for typically[1] recurving typhoons, "virtually all reach their peak intensity at, or a little before, the point of recurvature." Climatological studies showing the monthly mean distribution of intensity changes for western North Pacific tropical storms and typhoons (Brand and Gaya, 1971; Leichty, 1972) tend to support the findings of Riehl. Huntley (1981) and Cheng-Lan and Sadler (1982) also looked at the monthly mean distribution of the intensity of recurving tropical cyclones in the northwest Pacific and recognized the high variability of maximum intensity around the point of recurvature. An examination of all recurving tropical storms and typhoons from 1965 through 1982 revealed that 33% intensified after recurvature, some more than 72 hours afterward. Huntley found that 30% of the 1970-1979 tropical cyclones reached maximum intensity after recurvature. Cheng-Lan and Sadler looked at the intensity of recurving typhoons during the same period and found that 20% reached maximum intensity 18 hours or more after recurvature. During 1978, 65% continued to intensify after recurvature: Typhoon Irma (September) intensified for 84 hours and Tropical Storm Tess (November) intensified for 81 hours. Typhoon Flossie (September 1966) attained its maximum intensity 96 hours after it recurved. September and October typhoons (1971-1977) that intensified after recurvature had 42% greater 24-hour and 48-hour intensity forecast errors than the average for these two months during the same period. This increased number of forecast errors had a distinct negative bias, indicating forecasters anticipated weakening too soon.

This study examines various characteristics of tropical storms and typhoons that intensify after recurvature, including the mean monthly distribution and relationship to the oceanic and meteorological environment. The results will hopefully provide insight leading to better intensity forecasts.

2. CRITERIA.

To provide the operational forecaster a comprehensive view of the intensity behavior of recurving tropical cyclones, the author has established liberal criteria to allow examination of "atypical" cases as well as "typical" ones. This study examines 18 years (1965-1982) of western North Pacific tropical cyclone data. All tropical cyclones during this period meeting the following criteria were used in this study:

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[1]Riehl considered only typhoons which had at least a 3-day history, reached at least 30N, had an initial westward movement, reached typhoon intensity in the tropics, and did not move over significant land masses.

a. The tropical cyclone had to recurve. The point of recurvature is defined as the most poleward point at which the tropical cyclone's movement changes from a westward component to an eastward component being steered by the mid-latitude, mid-tropospheric westerlies.

b. Tropical cyclones recurving over land areas were considered unless the land caused total dissipation or the system was undergoing extratropical transition. This considered reintensification of tropical cyclones that moved over land and then back over water after recurving.

c. The tropical cyclone had to attain a minimum intensity of 34 knots (17.5 ms^{-1}) at sometime in its life.

Of the 478 tropical storms and typhoons occurring from 1965 through 1982, a total of 181 (38%) met the above criteria and were used in this study. To be considered as intensifying after recurvature, the tropical cyclone's intensity had to exceed that at recurvature by at least five knots, at least six hours after recurvature.

3. DISCUSSION AND RESULTS.

a. General Observations.

From 1965-1982, 60 tropical cyclones intensified after recurvature. This represents 13% of the total and 33% of the recurvers. Table 1 lists the monthly distribution of all tropical cyclones (1965-1982), the monthly distribution of recurvers, the monthly frequency of recurvature, the monthly mean latitude of recurvature (MLR), the latitudinal range of recurvature, the longitudinal range of recurvature, and the favored longitudes of recurvature. (The latter parameter is more useful to the operational forecaster than the mean longitude of recurvature which can be misleading since it is often located in a region of low recurvature frequency between two regions of high recurvature frequency.)

An initial study, based on 1965-1977 data, identified several characteristics of tropical cyclones that intensify after recurvature. These characteristics were evaluated for their usefulness in operational forecasting using 1978-1982 recurving tropical storms and typhoons. The characteristics of the two data sets adhered closely. The following discussion describes the unique characteristics of tropical cyclones that exhibit intensification after recurvature (IAR) and establishes rules for recognizing and forecasting such behavior.

Table 2 and Figure 1 show the monthly distribution of those recurvers that intensified after recurvature. Two distinct peaks are noted: May-June and September-October. During the first peak, 60% of the recurvers underwent IAR, and during the second peak, 35% exhibited the behavior. These peaks can be expanded to include March-June and August-November with somewhat less frequency of occurrence (see Table 2). No cases were observed in July. Nearly all winter and spring tropical cyclones exhibiting greater than 10 kt (5.1 ms^{-1}) IAR recurved equatorward of the monthly MLR. The same was true for summer and autumn tropical cyclones exhibiting greater than 15 kt (7.7 ms^{-1}) IAR. The MLR for each month is shown in Figure 2. These values differ slightly from those found by Huntley (1981)

Table 1. Recurvature statistics based on tropical cyclones (TC) occurring from 1965 to 1982, inclusive. Month is the month of recurvature. REC means recurvature or recurving.

MONTH	# TC	# REC	% REC	LATITUDE OF REC RANGE/MEAN		LONGITUDE OF REC RANGE/FAVORED	
Jan	11	5	45		16N		
Feb	4	1	25		15N		
Mar	12	5	42		16N		
Apr	16	10	63	13-21N	17N	108-145E	125-130E 135-145E
May	20	14	70	14-23N	18N		116-126E 140-145E
Jun	29	13	45	13-27N	20N	111-160E	112-122E 130-135E
Jul	75	8	11	23-36N	29N	124-162E	124-129E 140-145E 160-165E
Aug	91	27	30	23-37N	30N	125-155E	123-131E 138-148E
Sep	90	44	49	19-37N	26N	124-161E	124-152E
Oct	68	33	49	14-30N	22N	121-163E	126-136E 140-151E
Nov	44	16	36	16-22N	20N	111-151E	126-132E 135-137E 145-151E
Dec	18	5	28	14-19N	17N	112-130E	112-113E 119-130E
TOTAL	478	181	38%				

Table 2. Intensification After Recurvature (IAR) statistics based on tropical cyclones (TC) occurring from 1965 at 1982, inclusive. REC means recurvature. Month refers to month of recurvature.

MONTH	TOTAL RECURVERS	TOTAL WITH IAR	RECURVERS WITH IAR (%)		
Jan	5	2	40		
Feb	1	0	0		
Mar	5	3	60		
Apr	10	2	20		
May	14	8	57	60%	50%
Jun	13	8	62		
Jul	8	0	0		
Aug	27	5	18		
Sep	44	15	34	35%	30%
Oct	33	12	36		
Nov	16	4	25		
Dec	5	1	20		
TOTAL	181	60	33%		

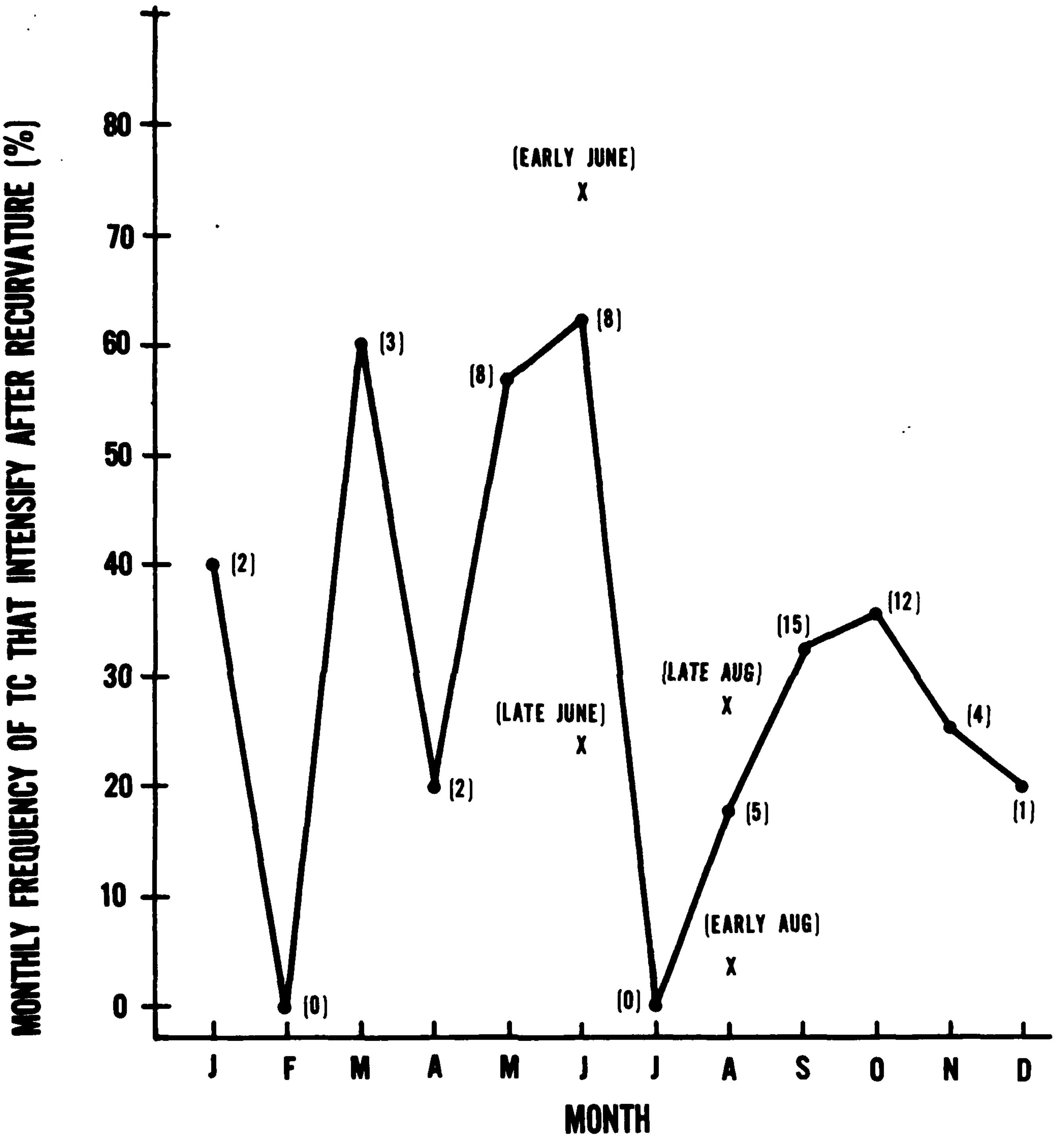

FIGURE 1. Mean monthly frequency of tropical cyclones (TC) that intensify after recurvature (from Table 2). Total cases in parenthesis. Note that late June and early August will have lower than mean monthly frequency as they exhibit July characteristics. Xs are qualitative, not actually measured.

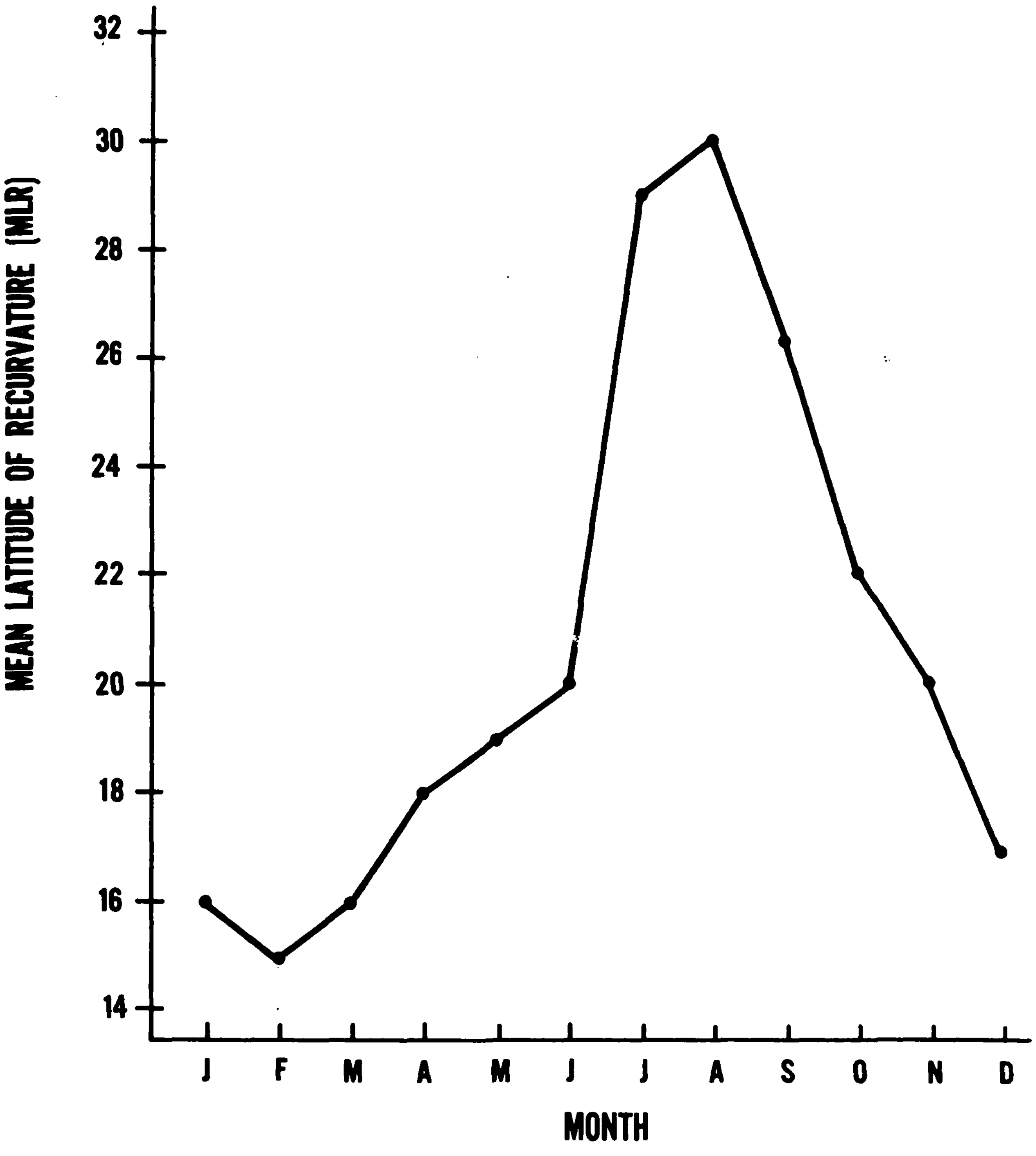

FIGURE 2. Monthly mean latitude of recurvature for all recurving tropical cyclones from 1965 - 1982.

probably because of the sample size, the half monthly values provided by Huntley, and to some extent, the differences in the selected recurvature points in cases where the recurving storms traversed a broad subtropical ridge or exhibited a long period of northward movement.

Tropical cyclones attaining an intensity greater than 90 kt (46.3 ms^{-1}) at or before recurvature did not normally intensify significantly after recurvature. An exception is noted in the region of the Kiroshio Current where the threshold intensity was found to be 105 kt (54 ms^{-1}). More than 95 percent of the post-recurvature intensifiers ceased intensification at or south of the monthly mean 26.6°C sea surface isotherm. For a given month, the farther equatorward of the MLR that recurvature occurred, the longer was the duration of IAR. No IAR was observed poleward of the monthly mean 23.9°C sea surface isotherm, and weakening was frequently slow equatorward of it.

Nearly all June and August through early November tropical storms and typhoons which exhibited IAR more than 12 hours after recurving, acquired a track north of northeast soon after recurvature. Winter and spring systems exhibiting this behavior frequently acquired an eastnortheast to eastward track. Many of the cyclones undergoing IAR (especially those in June, September, October, and November) displayed irregular tracks at or near recurvature; e.g., loops, kinks, and large directional changes over a small latitudinal displacement (Figure 3). This erratic movement was also noted by Cheng-Lan and Sadler (1982).

b. Synoptic/Dynamic Influences.

A particular synoptic pattern was associated with irregular tracks. A mid-latitude trough deepens and digs unseasonably equatorward while simultaneously, the axis of the mid-tropospheric subtropical ridge (STR) east of the trough shifts rapidly equatorward.[2] As the trough digs toward the tropics, it remains quasi-stationary or retrogrades slightly. Winds on the eastern side of the trough acquire a more southerly component, allowing the STR to broaden in a poleward direction. As a tropical cyclone (TC) approaches the southeastern periphery of the trough, recurvature is suddenly induced well south of the MLR. As the sequence occurs, the northwestward moving TC frequently responds by rapidly ceasing its westward movement, and looping or kinking before becoming sufficiently influenced by mid-latitude westerlies to acquire a north-northeastward track. Figure 4 illustrates the sequence. The broad ridge to the east will occasionally develop a distinct secondary ridge axis several degrees latitude poleward of the primary axis. As the TC traverses the region between the two axes, the speed of movement remains relatively constant.

Whenever this process occurs, certain physical parameters become favorable for intensification of weak and moderate tropical cyclones and/or slower than normal weakening of intense typhoons. These parameters are:

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[2]During Typhoon Sally (June 1976) the STR axis shifted approximately 400 nm (741 km) in less than 12 hours.

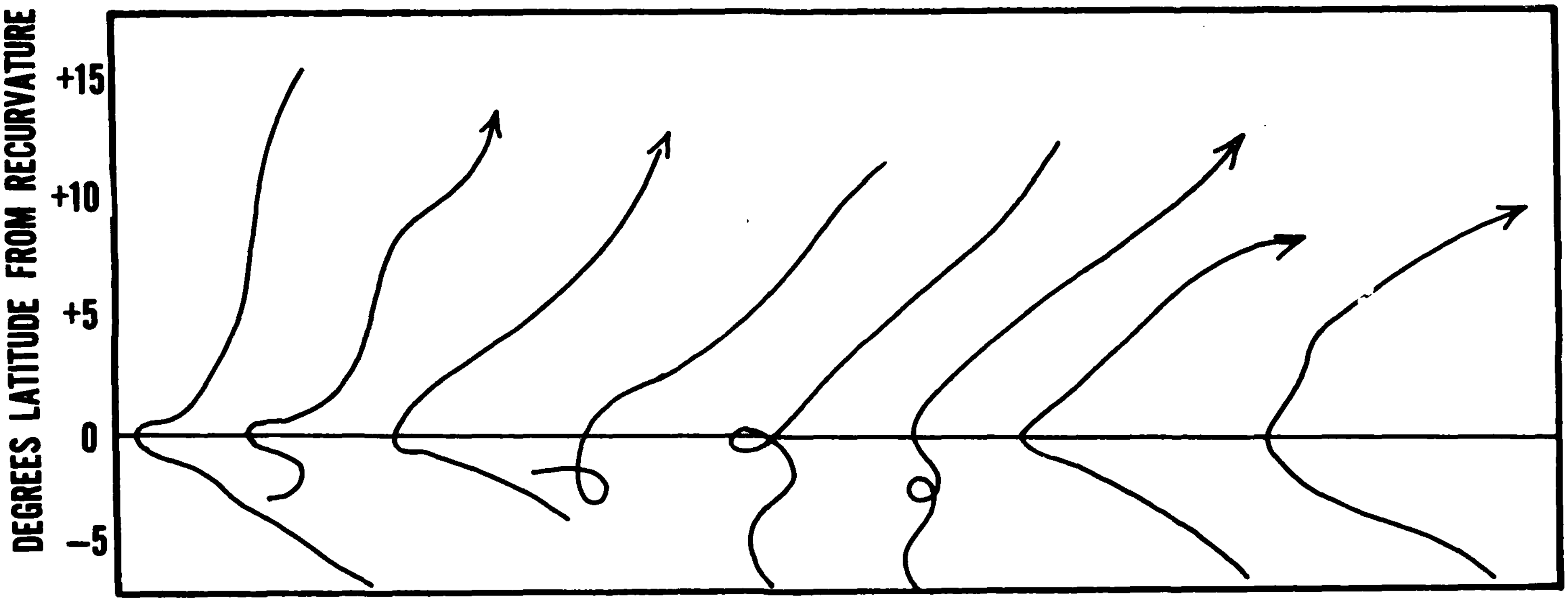

FIGURE 3. Characteristic tracks of tropical cyclones that intensify after recurvature.

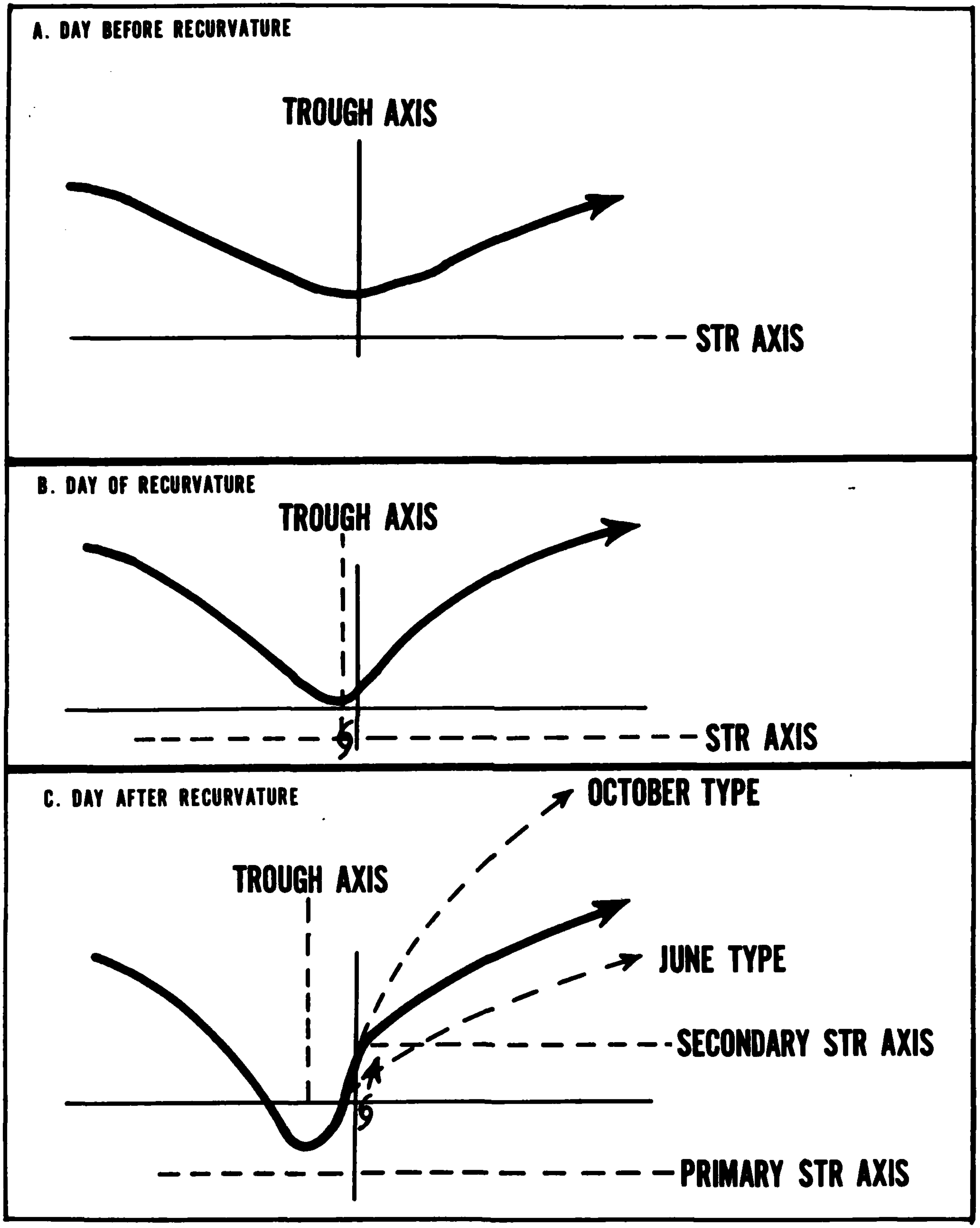

FIGURE 4. Sequence of events most frequently observed with Tropical Cyclones (TC) that intensify after recurvature. (a) About the day before recurvature, a TC approaches a mid-tropospheric, mid-latitude trough. (b) About the day of recurvature, the trough digs unseasonably equatorward, the TC moves erratically and, influenced by westerly steering, begins to recurve. (c) About the day after recurvature, the TC, still influenced by little vertical shear, warm sea surface temperatures, and enhanced outflow, continues to intensify.

(1) Vertical Shear. It is common knowledge that the most destructive force affecting recurved TCs is strong westerly wind shear. As the TC moves northward, the shear degrades successively lower levels of the vertical structure (Figure 5a). (Dropco (1981) discussed the detrimental effects of mid and low level wind shear.) However, when the deep (high amplitude) quasi-stationary trough described above (Figure 5b) induces recurvature, the westerly winds have a larger southerly component than a westerly one. As the TC traverses the broad ridge, it parallels the jet axis rather than cutting across it as in a typical situation. Thus, the shear affects the western periphery of the TC, but does not degrade the storms internal vertical structure. This situation frequently lasts several days. Apparently, the intense warm advection from the TC enhances the strength of the "locking high" east of the trough, preventing eastward movement of the trough. Figure 6 shows the monthly mean latitude of the 300 mb, 25 kt (12.9 ms^{-1}) and 50 kt (25.7 ms^{-1}) isotachs minus the MLR. From this we see that shear will tend to be great from late November-April, and weakening after recurvature will usually be rapid. However, during this period, if the TC moves toward the east after recurvature (not into increasingly greater shear), there will be minimal affect by the shear and it will weaken more slowly. Typhoon Lucy (November-December 1977) is an example of such a case.

(2) Enhanced Outflow. Numerous authors (Guard, 1977; Sadler, 1976 and 1978; and Ramage, 1974) have indicated the importance of outflow channels for TC intensification. The strongly meridional flow associated with the high amplitude trough (Figure 5b) allows the vorticity advection to be oriented along the TC track instead of across it (Figure 5a). The strongly divergent upper level winds northwest of the TC provide an excellent outflow channel, conducive to intensification. It was observed that no IAR occurred during July. Note that 50 kt (25.7 ms^{-1}) winds are absent in July and August (Figure 6). This isotach gradient is very weak and any outflow channel to the north is very inefficient. More on outflow channels will be discussed in paragraph 3.b.5.

(3) Sea Surface Temperature (SST). Whenever recurvature occurs equatorward of the MLR, the post-recurvature phase will have longer access to warm SST than when recurving at or poleward of the MLR. Figure 7 illustrates the monthly mean latitude of the 26.6°C SST isotherm minus the MLR at selected longitudes in the western North Pacific for each month. Figure 8 illustrates the same relationship using the 23.9°C SST isotherm. Definite peaks exist for May-June and for August-November. A pronounced valley is present in July. These correspond identically to the peaks and valleys observed in the frequency of TC undergoing IAR. As stated earlier, nearly all IAR occurred equatorward of the 26.6°C sea surface isotherm and slow weakening generally occurred equatorward of the 23.9°C sea surface isotherm. Undoubtedly, the depth of the ocean mixed layer is an important consideration as well.

(4) Movement. Those TCs that recurve at unseasonably low latitudes usually must traverse a broad mid-tropospheric STR. Therefore, stearing currents remain relatively weak longer than with more normal recurvers. As stated earlier, if a secondary ridge axis develops, the speed of movement will remain relatively constant between the two axes. If the

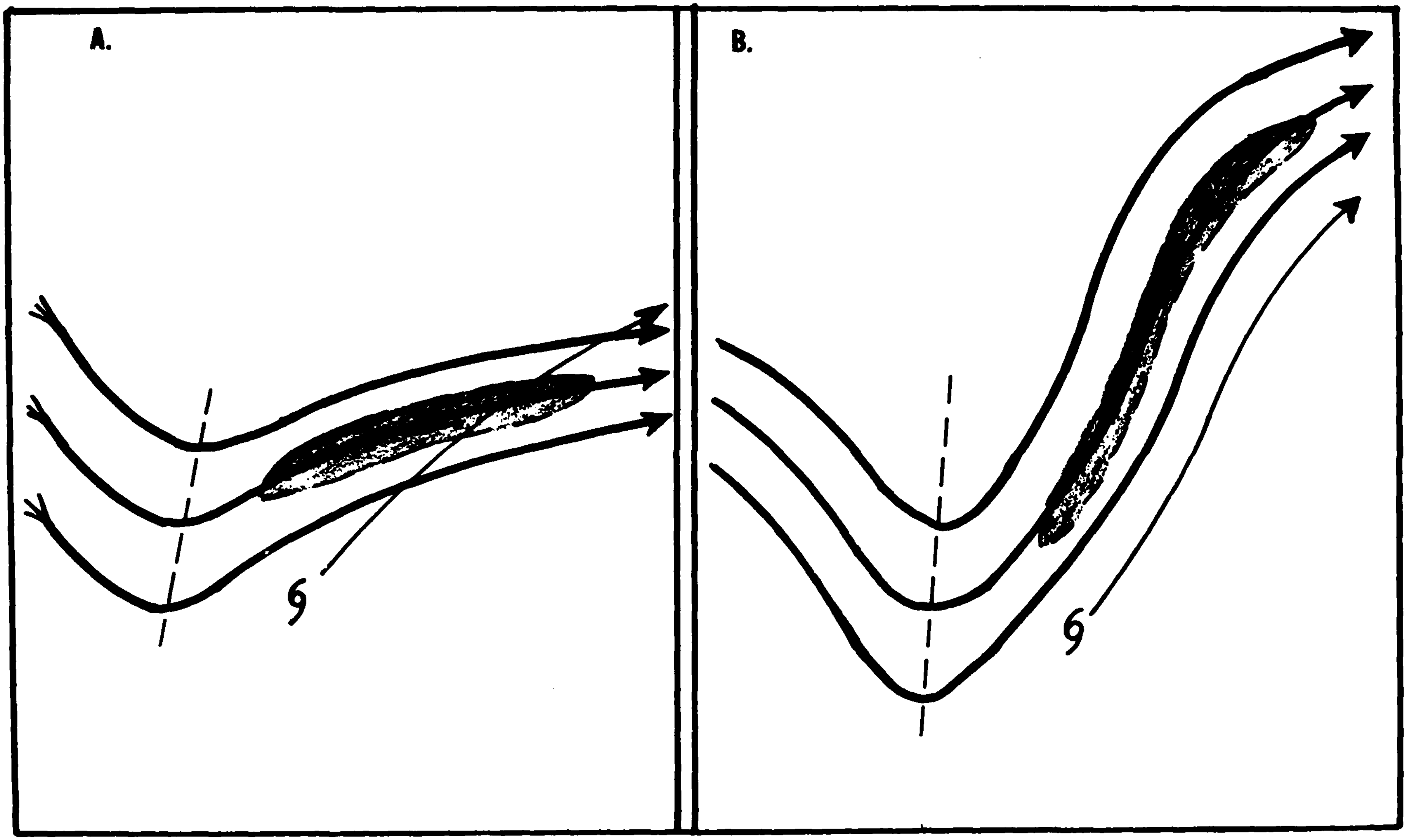

FIGURE 5. Comparison of 500 mb flow (heavy solid line) and Tropical Cyclones (TC) movement (thin solid line) for more typical recurving TC (a) and for TC that intensify after recurvature (b). Heavy dashed line shows jet core and thin dashed line shows trough axis.

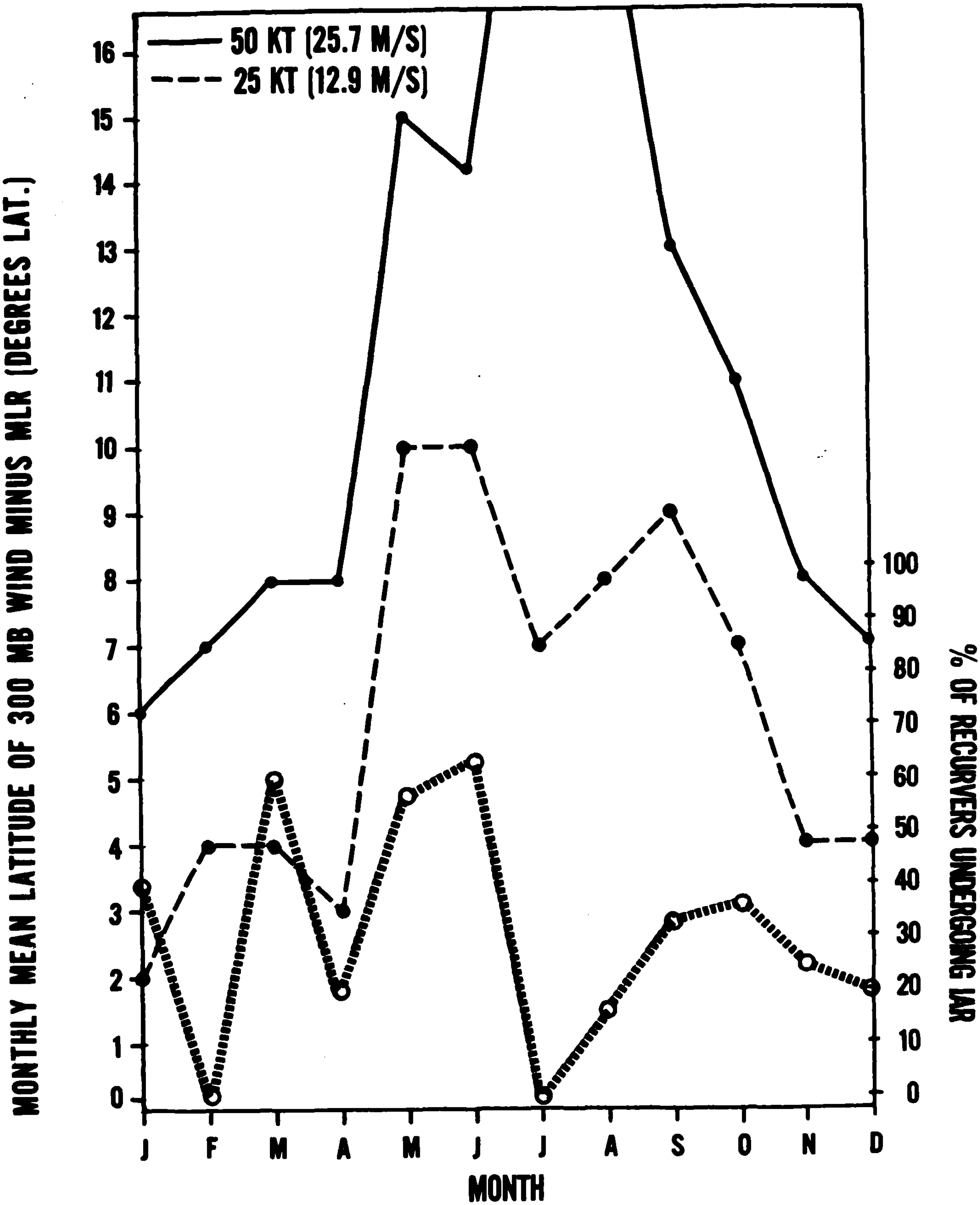

FIGURE 6. Monthly mean latitude of 300 mb 50 KT (25.7 msec -1) (solid) and 25 KT (12.9 msec -1) (dashed) winds minus the monthly mean latitude of recurvature for the western north Pacific. The dotted line shows the monthly frequency of tropical cyclones exhibiting intensification after recurvature.

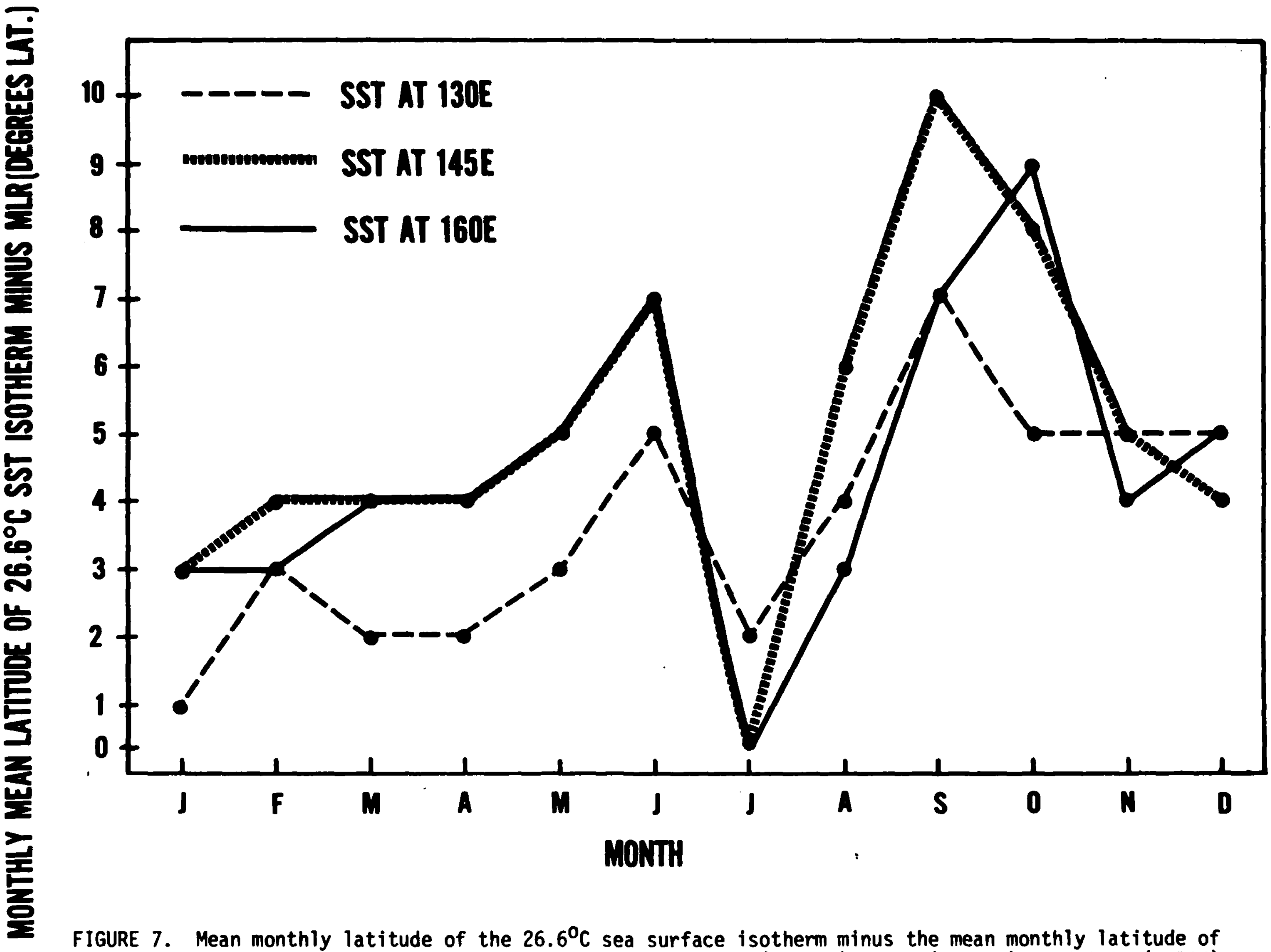

FIGURE 7. Mean monthly latitude of the 26.6^{o}C sea surface isotherm minus the mean monthly latitude of recurvature for the western north Pacific at 130E (dashed), 145E (dotted), and 160E (solid).

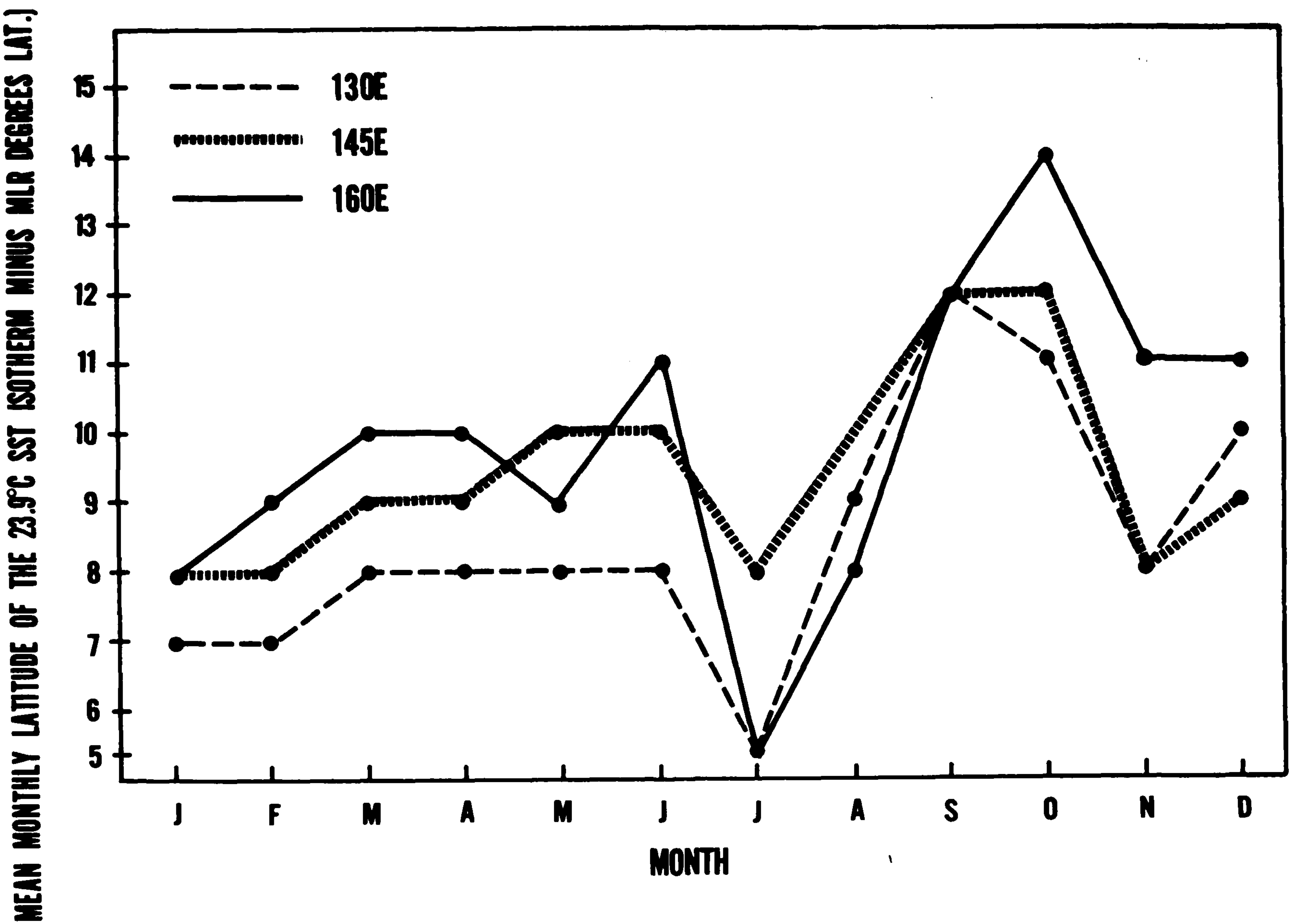

FIGURE 8. Mean monthly latitude of the 23.9°C sea surface isotherm minus the monthly mean latitude of recurvature for the western north Pacific at 130E (dashed), 145E (dotted), and 160E (solid).

northwestern periphery of the mid-level STR is more hyperbolic shaped, the TC will accelerate but the acceleration will be more gradual than with more normal recurving TCs. As a result, the TC approaches a sheering environment more slowly, maintains an efficient outflow channel longer, and remains over warmer sea surfaces longer than would be the case with more rapidly accelerating TCs.

(5) Threshold. Cheng-Lan and Sadler (1982) and Huntley (1981) have shown that super typhoons reach their maximum intensity one to three days prior to recurvature. From my experience, super typhoon attainment requires two efficient outflow channels, one to the north and one to the south. From late June until early November, the tropical upper tropospheric trough (TUTT) usually provides the northern channel, while strong upper level northeasterlies accelerating toward the easterly jet over India or across the equator toward the Southern Hemisphere subtropical jet provided the southern channel. Once a TC approaches recurvature, the TUTT induced channel has been replaced by the relatively weak mid-latitude westerlies. In addition, the southern channel has become too far removed from the TC to provide an efficient outflow channel. The TUTT, now located south of the TC, may provide a southern outflow channel, but a much less efficient one than when it is located to the north. The loss of the second outflow channel limits the amount of IAR that can occur. Thus, TCs with an intensity of 90 kt (46.3 ms^{-1}) at recurvature usually do not undergo IAR. As was pointed out earlier, this treshold value is about 105 kt (54 ms^{-1}) in the region of the Kiroshio Current. This indicates that the ocean thermal potential (Gray 1975) determined by SST and mixed layer depth also plays some role in determining the upper threshold value.

c. A Month by Month Look at IAR.

The monthly distribution of IAR (Figure 1) is closely related to the differential heating between land and sea. Since recurvature in this study is defined by the relationship between the TC direction of movement and the mid-latitude, mid-tropospheric STR, the author assumes that the latitude of the mean monthly position of the 500 mb STR axis and the MLR is similar. Cheng-Lan and Sadler (1982) found the monthly MLR to be 2-4^{o} latitude poleward of the monthly mean 500 mb ridge line. This might suggest a steering current somewhat lower than the 500 mb level, but also reflects the significant number of TC that recurve equatorward of the mean position. The monthly mean latitude of the STR and the MLR are anchored by the planetary long wave pattern which is thermally and orographically anchored, primarily by the continents (Palmein and Newton, 1969). The high specific heat of water dictates that the meridional movement of SST lag that of the STR (MLR). This lag accounts, in part, for the shortlived IAR in Spring and the longlived IAR in Fall (See Figures 7 and 8). The following month by month look at IAR should provide useful guidance that the forecaster can use in deriving his/her intensity forecasts.

(1) December-April. The total number of recurving TCs during this period is small, especially during December and early January when the mean long wave is usually over Asia. For those TCs that do recurve, the potential for IAR is low since strong westerly shear and cooler SST are encountered soon after recurvature. When IAR does occur (usually March or April), it is limited to less than 10 kt (5.2 ms^{-1}) intensification and 12 hours duration after recurvature.

(2) May-June. By May, the westerlies have shifted poleward, reducing strong unidirectional shear on the northern periphery of the TC, yet still providing an efficient outflow channel to the north. Frequently, deep mid-latitude troughs dig toward the tropics and induce recurvature equatorward of the MLR. During such occurrences the STR is narrower and the warmer SST isotherms are much farther equatorward than in September and October (Figure 7). Thus, even though the potential for IAR is high in May and June, it is normally confined to 15 kt (7.7 ms^{-1}) intensification and 24 hours duration after recurvature. A TC which takes an eastward track can stay south of the 26^{o}C SST isotherm and south of extreme westerly shear. This would allow the TC to achieve greater and longer intensification as did Typhoon Ruby (June 1976). However, such occurrences are not common.

(3) July. July is an apparent paradox; a valley of very low IAR potential between two peaks of high IAR potential. In July the MLR jumps 8^{o} - 9^{o} northward as the STR becomes anchored by the Himalaya--Tibetan massif (Ramage, 1971). East of 140E the 26.6^{o}C SST isotherm moves only 3^{o} northward, while west of 140E the 26.6C SST isotherm moves 6^{o} northward, but mixed layer depths are shallow (15-30 m). Early recurvature is induced by equatorward TUTT-like extentions of weak mid-latitude troughs (Guard 1977). Once the TC recurves, the outflow channel to the north is weak since the mid-latitude westerlies during July are very weak and the outflow channel to the south is too far removed to be an intensification factor.

(4) August-Mid September. The IAR potential rises sharply during this period. From July to August the 26.6^{o}C SST isotherm moves as much as 6^{o} to the north while the MLR moves only 1^{o} - 2^{o} in the same direction. Simultaneously, mixed layer depths increase. As with July, early recurvature is induced by TUTT-like extentions of mid-latitude troughs. Mid-latitude westerlies are weak, imposing little shear but also providing a poor outflow channel. Thus, IAR is normally limited to 20 kt (10.3 ms^{-1}) intensification and 48 hours duration after recurvature. The weak outflow channel reduces the threshold intensity for IAR to 70 kt (36 ms^{-1}). Post-recurvature weakening is slow during this period.

(5) Mid September-October. IAR is very high during this period. The separation between the 26.6^{o}C SST isotherm and the MLR is greatest. The STR is no longer anchored near 30^{o}N and westerlies move equatorward. When deep trough trigger low latitude recurvature, the STR becomes extremely broad (Figure 4). (There may occasionally be more than 20^{o} latitude between the primary and secondary ridge axes.) The broad ridge exposes the TC to minimal upper and middle level westerly shear. Intense southerly flow just west of the TC provides a highly efficient outflow channel. IAR may exceed 50 kt (25.7 ms^{-1}) intensification and 72 hours duration after recurvature. Although the September IAR potential is very high, only 30% of the recurvers exhibit this behavior. This arises in part because a large number of September TCs are very intense and exceed the 90-105 kt (46.3 - 54.0 ms^{-1}) threshold above which IAR is not observed.

(6) November. Deep equatorward trough penetrations are common in November. IAR regimes resemble both that of June (narrow STR) and that

of October (broad STR). November TCs also exhibit dramatic, shortlived baroclinic intensification (Brand and Guard, 1979). This behavior may have, in some cases, been reflected in the Joint Typhoon Warning Center (JTWC) "best track." If so, the November IAR frequency may be somewhat high. Also November TCs are frequently intense and exceed the IAR threshold.

d. Perspectives.

(1) The study revealed a strong relationship between the monthly distribution of IAR and the monthly distribution of SST. Ramage (1974) showed that the upper level, peripheral environment of the TC is a much more important determinant of intensification than is SST. However, most TCs that intensify after recurvature have similar upper level environments (Figure 5). This, in essence, removes the environment as a variable when considering TCs that intensify after recurvature, and allows the effect of SST differences to play a more dominant role than would be observed in most other cases of recurvature.

(2) This study, as are most, is based on "post-storm" data, and utilizes knowledge of a TC's behavior not available to the operational forecaster who is plagued with determining the future behavior. The forecaster must depend primarily on forecast models to ascertain the future TC environment. Another important tool can be the knowledge of seasonal or monthly changes in TC behavior such as climatology. This can help the forecaster assess the potential for certain types of behavior. The value of this study is to increase the forecaster's knowledge of the environmental factors influencing certain TC behavior as well as to provide a physical understanding of the processes involved. The study may have limited value before recurvature occurs, but should be a powerful forecaster aid at, or shortly after, recurvature.

4. CONCLUSION AND RECOMMENDED RESEARCH.

This study reveals certain characteristics of TCs that intensify after recurvature. The identified relationships between these post-recurvature intensifying cyclones and their environment should provide the forecaster much useful information to assess the potential for such occurrences. Once the potential is recognized or once characteristic erratic movement is observed, the forecaster should be able to forecast intensity using the information/rules provided in this study. Hopefully, smaller intensity forecast errors will result. The same physical rationale should afford the forecaster a better feel for the relationship between the TC environment and the rate of weakening. Gray (1975) pointed out the importance of ocean thermal potential for TC genesis. Western North Pacific TC virtually always have sufficient ocean thermal potential at latitudes where genesis occurs. I see much more useful application of this potential for determining weakening or intensification after recurvature.

MLR is used as a reference point to assess the IAR potential. MLR data is also presented by Burroughs and Brand (1972) and by Huntley (1981). Although Huntley's study covers half the period of this study, it provides half-monthly MLR which may help to further refine the forecaster's ability to predict post-recurvature intensity.

From my experience the forecast models do not handle the abrupt, equatorward mid-latitude trough movements well. This study will at least flag to the forecaster the chance for such movement. Once fix platforms indicate that erratic movement may be occurring, the forecaster should be more open to accepting such movement and more capable of anticipating subsequent behavior.

Numerical modeling is looked to as the "hope of the future" for providing the "big breakthrough" in reducing TC forecast errors. Must we wait, or can we afford to wait for the "big breakthrough?" This author thinks not on both counts.

I'm convinced that we can improve our TC forecasts. JTWC does a respectable job on two-thirds of their TCs each year (Figure 9), with average errors of 100, 200, and 275 nm for 24, 48, and 72 hour forecasts, respectively. The remaining one-third exhibit 24, 48, and 72 hour forecast errors of 175, 350, and 550 nm, respectively. I'm confident that by studying cases and classes of TCs that exhibit "unusual" behavior, we can nibble the overall average errors to the lower range. Studies of this type can be done using satellite data, conventional data, and climatological data, all readily available data sources. Unfortunately, it is not enough just to have the data available. It takes about two typhoon seasons before a forecaster has sufficient experience to perform productive, non-statistical technique development. Most forecasters are near the end of their assignment at JTWC by then. Those that are allowed to remain longer, must be afforded the opportunity to develop, document, and evaluate new techniques. Much of the lack of improvement in forecast errors stems from the fact that each successive cadre of forecasters spends its time relearning the lessons of their predecessors.

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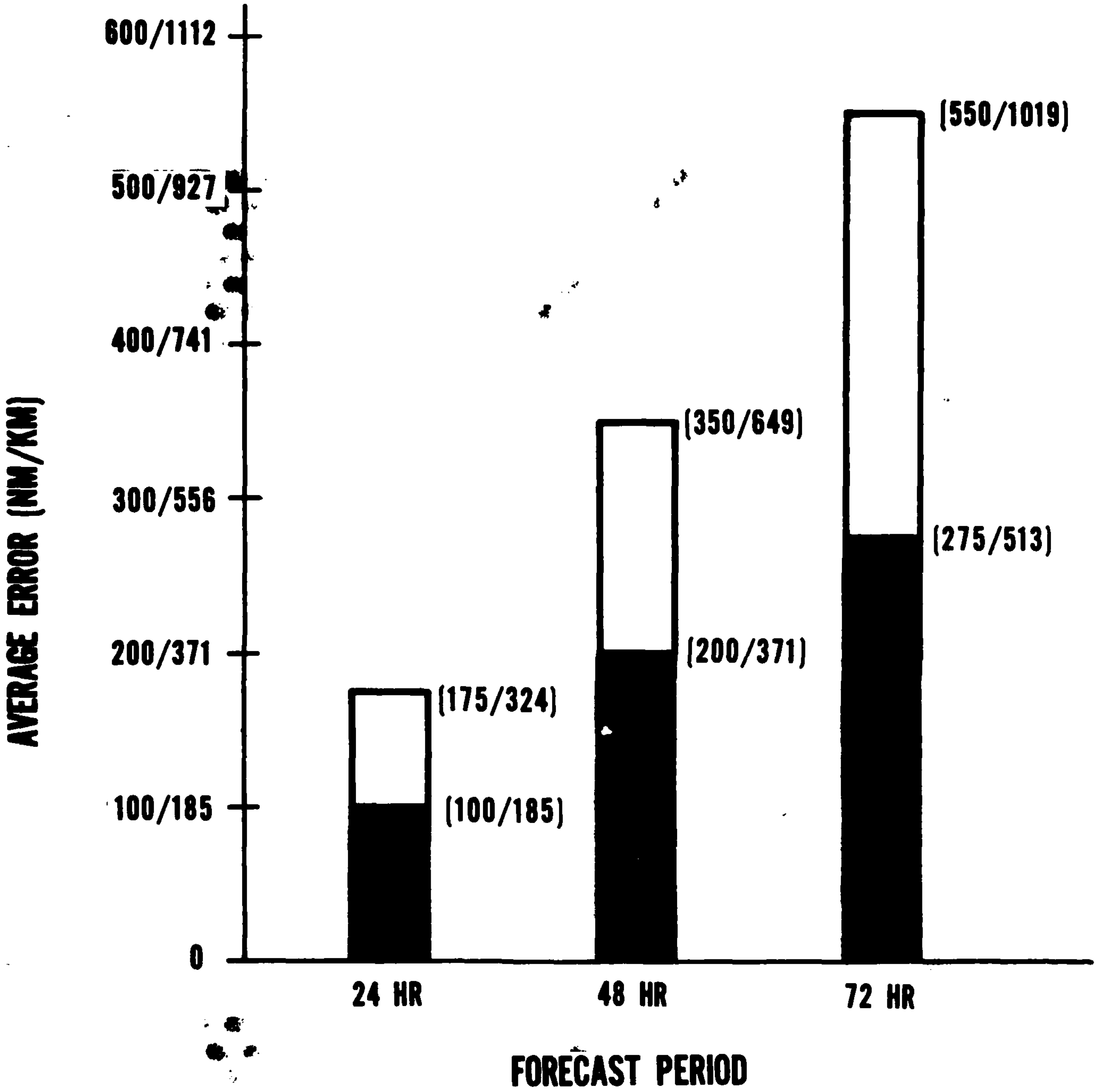

FIGURE 9. Bar graph depicting the average 24. 48, and 72 hour JTWC forecast errors for western North Pacific Tropical Cyclones (TC). The solid bars indicate average errors of well forecast TC which constitute two-thirds of all TC. The total bars (solid plus open) indicate average errors of poorly forecast TC which constitute one-third of all TC. The sample includes all TC from 1978 - 1982, inclusive.

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